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The implicit checking of lexical relation between verbs and objects in the processing of case information: an ERP study

動詞句の格情報処理における意味的関連性の潜在的な照合 ——事象関連電位による検討——

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Abstract
This study examined how case information and lexical relation between verbs and objects were processed in the brain. While an influential model of sentence processing proposed that the independent and parallel processing of syntax and semantics occurred around 400 ms after the processing of linguistic stimuli, some studies argued that syntactic and semantic information interacted with each other in this time window. Although these studies regarded gender information as syntactic, the information is encoded in the lexical entry of words, which suggests that violations related to the information may not be syntactic in nature. Rather than the interaction of syntax and semantics, these studies suggest that when two types of information are both encoded in the lexical entry of words, the processing of one type of information interacts with that of the other type of information.

In Japanese, there are verbs which selectively take the accusative-marked or dative-marked objects as their arguments. When objects are marked with the accusative case, “wo” is attached to the objects. When objects are marked with the dative case, “ni” is attached to the objects. Previous studies of Japanese case markers proposed that information about what type of case verbs assign to their objects was encoded in the lexical entry of the verbs. Considering that case and semantic information of verbs needs to be retrieved from their lexical entries, we hypothesized that the processing of case information would interact with lexical-semantic processing of the verbs.

In the present study, using above types of verbs, we constructed two-word sentences composed of verbs and objects. By crossing the correctness of case information and lexical relation between verbs and objects, we created four types of test sentences, by which we can investigate the interaction of the two types of processing. The correctness of case information depended on whether the case required by verbs corresponded to the case of objects. The correctness of lexical relation depended on whether verbs and objects are lexically related. Two types of judgment tasks were used; one was a phrase task, the other was a lexical task. The phrase task required participants to judge the case which a verb assigns to its object corresponded to the case of the object. The lexical task required participants to judge whether the successively presented object and verb were lexically related or not. These tasks were used to examine the processing of case information and lexical relation independently. We also varied the interstimulus interval (ISI) between the

objects and verbs, which created the two ISI conditions (100 ms and 500 ms). The two judgment tasks and two ISI conditions resulted in the four experimental conditions.

We recorded event related potentials which were elicited in response to the presentation of verbs. Both case violations and lexical anomalies elicited the N400, the former of which suggests that the case violations were detected when the parser identified the case information of verbs encoded in their lexical entries. The amplitude of the N400 was also different between case violations and lexical anomalies. In addition, when participants performed the phrase task, a similar amount of negativity was elicited in semantically anomalous sentences regardless of whether the sentences included case violations. This indicates that even in the processing of case information, the lexical relations were predominantly processed in the brain. While similar results were obtained in the two ISI conditions, the main effect of Task was observed in the ISI 100 ms condition but not in the ISI 500 ms condition. A significantly larger negativity was elicited in the phrase task under the ISI 500 ms condition when sentences included case violations and lexical anomalies than when sentences included only case violations. This shows that deeper processing of the stimuli due to the longer ISI enabled the detection of lexical anomalies in sentences with case violations.

The results of this study demonstrate the following two points: (1) Case violations elicit the N400. (2) The processing of case information is not independent of that of lexical relation. We consider that case violations and lexical anomalies elicited the same ERP component (i.e. N400) since the processing of case information and lexical relation needs access to the lexical entry of verbs. From the result that lexical relation between verbs and objects was predominantly checked in the processing of case information, we argue that the processing of lexical relation is necessary for the parser to check whether the noun phrases act as objects for verbs. Unless verbs and objects are lexically related, the parser is not able to determine the correct case to be assigned by verbs to their objects. In this sense, our findings suggest that the processing of case information interacted with that of lexical relation. Since the interaction between the processing of case information and lexical relation was observed at the N400 time window, the results of the present study suggest that the interaction between the two types of lexically encoded information occurs earlier than the interaction of syntax and semantics in a sentence at the P600 time window.

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Chapter 1 Introduction

In sentence comprehension, different types of information (e.g. syntax, semantics) have to be integrated at certain stages of linguistic processing. One major concern for research of language is how and when these types of information converge on one specific interpretation of a sentence. Especially, there are debates about the primacy of syntax over other linguistic information. Syntax-first models (Ferreira & Clifton, 1986; Frazier, 1987; Frazier & Rayner, 1982) assumes that initial stage of language processing consists of building local phrase structure only based on word category information while interactive models (MacDonald, Pearlmutter, & Seidenberg, 1994; Trueswell, Tanenhaus, & Garnsey, 1994) assumes that information other than word category is also used in the early stage of sentence processing. However, these models cannot make clear statements as to exactly when syntax and other information are integrated since they are based on the findings from eye tracking studies. As integration processes of linguistic information occur in the brain, they need to be investigated by measuring brain activity during sentence processing.

Based on the findings from electrophysiological studies, in which researchers investigate brain activity on the order of milliseconds, Friederici proposed a model of sentence processing (Friederici, 2002, 2011; Friederici & Weissenborn, 2007). Her model assumes that sentence processing consists of three phases. In phase 1, local phrase structure is built based on word category information. In phase 2, thematic roles are assigned to arguments of verbs based on the morphosyntactic and semantic/thematic information. The integration of syntactic and semantic information occurs in phase 3. The following ERP components are elicited by violations in each phase: the early left anterior negativity (ELAN) for phase 1; the left anterior negativity (LAN) and N400 for phase 2; the P600 for phase 3.

Although her claim that word category has primacy over other information in early latencies is supported by a number of studies (Friederici, Steinhauer, & Frisch, 1999; Frisch, Hahne, & Friederici, 2004; Hahne & Friederici, 1999, 2002; Isel, Hahne, Maess, & Friederici, 2007; Rossi, Gugler, Hahne, & Friederici, 2005), studies have not provided coherent results about the processing in phase 2. Initially, the model proposed that morphosyntactic and semantic violations would elicit a LAN and N400, respectively. Since the LAN and the N400 were additively observed in response to the syntactically and semantically violated sentences (Gunter, Friederici, & Schriefers, 2000; Gunter, Stowe, & Mulder, 1997), the parallel and independent processing of syntax and semantics was assumed in this phase (Friederici & Weissenborn, 2007). However, two studies suggested the possibility that this parallel processing interacts with each other (Hagoort, 2003; Wicha, Moreno, & Kutas, 2004). Both studies observed that syntactically and semantically violated sentences elicited a larger N400 than semantically violated sentences. Friederici & Weissenborn (2007) argued that the results of these studies were due to the fact that gender disagreement was used as syntactic violations. They suggested that since gender information is encoded in the lexical entry of words, gender disagreement is likely to interact with semantic information. Given this argument, the results of Hagoort (2003) and Wicha et al. (2004) can be considered as follows: when two types of information are both encoded in the lexical entry of words, the processing of one type of information interacts with that of the other type of information at the N400 time window. This type of interaction may occur between the processing of information other than gender and that of semantic information. For example, in case assignment, verbs assign certain cases to noun phrases which act as their arguments. The information of case assigned by verbs to noun phrases is proposed to be in the lexical entry of the verbs (Ishiwata, 1999). Given that, the processing of this information may interact with that of sematic information.

As we mentioned above, in the N400 time window where Hagoort (2003) and Wicha et al. (2004) observed the interaction, two ERP components are generally elicited: the LAN and N400. The LAN is a negativity which appears from around 300 to 500 ms in the left-anterior region of the scalp (Barber & Carreiras, 2005; Caffarra & Barber, 2015; Osterhout & Mobley, 1995). Since it has been observed in sentences with morphological deviations (e.g. agreement mismatch), the LAN is considered to reflect the detection of morphological violations (Molinaro, Barber, & Carreiras, 2011). The N400 is a negativity which peaks about 400 ms after the onset of the critical word (Kutas & Hillyard, 1980). It is elicited in response to words which are semantically anomalous or unexpected from the previous context. To date, there have been two main views about the functional interpretation of the N400; one focuses on lexical access (Kutas & Federmeier, 2000, 2011; Lau, Phillips, & Poeppel, 2008) and the other on semantic integration (Baggio & Hagoort, 2011; Brown & Hagoort, 1993; Hagoort, Hald, Bastiaansen, & Petersson, 2004). The former suggests that the N400 reflects the cost of lexical access to incoming words while the latter proposes that the N400 reflects the difficulty to integrate meaning of encountered words with previous context.

ERP studies have been conducted to investigate how case is processed in the brain. Languages like German and Japanese use case marking system; objects are morphologically marked with the accusative or dative case. It is necessary for noun phrases in a sentence to be marked with the correct case. Otherwise, the whole sentence will be anomalous. To date, there have been studies about two types of case violation. One is placing the two identically case-marked noun phrases in a sentence. The other is manipulating the case of a noun phrase so that it does not match the case required by a verb. Compared to the former, a small number of studies have been conducted about the latter type of case violation. There are two studies about this type of violation in languages except Japanese: one in English (Coulson, King, & Kutas, 1998) and the other in German (Friederici & Frisch, 2000). Both studies observed a LAN and P600 when participants were presented with sentences which included case violations. The authors in the former study proposed that the LAN reflected the operation of working memory while those in the latter study proposed that it reflected violations of argument structure.

Before turning to the case violation studies of Japanese, let us briefly mention the basic characteristics of Japanese. First, the basic word order of Japanese is a subject-object-verb (SOV). Second, subjects can be omitted in sentences. Third, most importantly, Japanese has verbs which selectively take the accusative-marked or dative-marked noun phrases. There is a database about constructions of verbs in Japanese (Ikehara et al., 1999). This database describes what kind of construction each verb forms and based on the construction what type of case marker is assigned to noun phrases as arguments of the verb. Transitive verbs can be classified into four types: (1) those which only take noun phrases with the accusative case markers “wo” (hereinafter referred to as wo-verbs); (2) those which only take noun phrases with the dative case markers “ni” (hereinafter referred to as ni-verbs); (3) those which take both types of case-marked noun phrases; (4) those which take noun phrases with case markers other than “wo” and “ni”. When wo-verbs are combined with noun phrases marked with “ni” or when ni-verbs are combined with noun phrases marked with “wo”, sentences including them are anomalous. In other words, these verbs selectively assign “wo” or “ni” to the noun phrases which act as their objects. The correctness of phrases composed of noun phrases and wo- or ni-verbs depends on whether the case assigned to noun phrases by the verbs corresponds to the case marker of the noun phrases. It is proposed that the information about what type of case verbs assign to their objects is encoded in the lexical entry of verbs (Ishiwata, 1999; Muraki, 2000). For the parser to judge the correctness of sentences, this information needs to be retrieved from the lexical entry of the verb and checked against the case marker of the object. Hereinafter, following the term used in Mueller, Hirotani, & Friederici (2007), we refer to this process as the processing of case information. We use this term since the present study is similar to Mueller et al. (2007) in that both studies examine case markers in Japanese and focus on the processing of case assigned by a verb. Mueller et al. (2007) created sentences with case violations by placing two identically case-marked arguments in a sentence. Sentences with two identically case marked arguments are anomalous since the same thematic role cannot be assigned by a verb. On the other hand, the present study manipulated a case marker attached to a noun phrase so that the case assigned by a verb does not correspond to the case marker of the noun phrase. While the case information is independent of the specific information of verbs in Mueller et al. (2007), the case information is encoded in the lexical entry of verbs in the present study.

In Japanese, there are several ERP studies which investigated the processing of case violation: Arao, Suwazono, Sakamoto, & Nakada (2007), Kobayashi, Kanamaru, Sugioka, & Ito (2007) and Yano (2018). In these studies, sentences with case violations were created by manipulating case markers attached to noun phrases. Note that objects come before verbs in Japanese sentences. Examining how case violations were processed in the brain, these studies aimed to make clear the processing of case information. Arao et al. (2007) and Kobayashi et al. (2007) used the same type of case violation. Noun phrases marked with the accusative case were combined with ni-verbs and noun phrases marked with the dative case were combined with wo-verbs so that sentences are phrasally ill-formed. Arao et al. (2007) reported a LAN to violations of wo-verbs and an N400 to violations of ni-verbs. They proposed that wo-verbs were morphosyntactic while ni-verbs were thematic in nature. On the other hand, Kobayashi et al. (2007) reported a biphasic N400 – P600 pattern in response to case violations of wo-verbs and ni-verbs. The authors suggested that information of the case verbs require is in the lexical entry of the verbs and that the N400 reflect that case violations were detected when the parser accessed the lexical information of verbs. The results of Arao et al. (2007) and Kobayashi et al. (2007) indicate that case violations using wo- and ni-verbs elicit the N400. Since the N400 is considered to reflect semantic process, it may not be syntactic process to check the case information encoded in the lexical entry of verbs against the case marker of the preceding noun phrases. Furthermore, given the proposal made by Kobayashi et al. (2007), this type of case violation can be considered similar to gender violations used in Hagoort (2003) and Wicha et al. (2004). Friederici & Weissenborn (2007) pointed out that gender information is encoded in the lexical entry of words; gender violations may be detected when the parser accesses the gender information encoded in words. In contrast to these studies, Yano (2018) observed a LAN and a P600; however, his study is different from the two studies above in that case violations occurred between subjects and verbs. Case violations were realized by converting the nominative case to accusative case.

While the previous studies examined the processing of case information manipulating only case markers, research of Japanese case markers suggests that lexical relation plays an important role in the processing of case information. Okuda (1983) proposed that when noun phrases with certain case markers and verbs formed a phrase, the phrase tended to have specific meaning. For example, a noun phrase with the accusative case marker "wo" and a verb form a phrase, the meaning of the phrase tends to be one of the following patterns. Examples of phrases in Japanese are shown in each pattern. Literal translations are also given in parentheses.

(1) Verbs act on noun phrases and the noun phrases represent things or people to be acted on (usually verbs cause a change in noun phrases).

    e.g. kurumi wo waru (walnut + an accusative case marker "wo" crack; crack a walnut)

(2) Verbs represent possessing or transferring property and noun phrases represent the property.

e.g. kane wo kasu (money + an accusative case marker “wo” lend; lend money)

(3) Verbs represent mental activity and noun phrases represent the object of the activity.

e.g. kako wo omoidasu (past + an accusative case marker “wo” recall; recall the past)

(4) Verbs represent movement and noun phrases represent place in which the movement occurs (although verbs are intransitive in this case).

e.g. yama wo noboru (mountain + an accusative case marker “wo” climb; climb a mountain)

Given this proposal, the processing of case information may be related to the processing of lexical relation between noun phrases and verbs. Due to this reason, in addition to the processing of phrasally incorrect sentences in which the case required by verbs does not correspond to the case of objects, the processing of sentences composed of lexically unrelated words needs be investigated. The influence of lexical relation on the processing of case information can be examined comparing the lexically related and unrelated sentences.

In the studies we mentioned above, participants were required to perform grammatical judgments. This type of judgment task only focuses on the processing of case information in the test sentences. Since the processing of lexical relation is less likely to be facilitated by grammatical judgments, another kind of task which demands this type of processing is necessary. It was reported that depending on the requirement of tasks, different ERP components were elicited (Hahne & Friederici, 2002). The authors required participants to judge overall correctness of the sentences in the first experiment. When participants were presented with grammatically and semantically incorrect sentences, an ELAN and a P600 were observed. In the second experiment, the authors required participants to judge semantic correctness of the sentences and not to focus on grammatical violations. In this case, an ELAN and an N400 were observed. These results show that different ERP components are elicited by directing participants' attention to the specific aspects of information conveyed by sentences.

The previous studies mentioned above indicate that case violations elicit certain ERP components (the LAN or N400). However, the studies did not investigate whether lexical relation had an influence on the processing of case information. In addition, although the results of Hagoort (2003) and Wicha et al. (2004) suggest that two types of information interacts with each other in the N400 time window when both types of information are encoded in the lexical entry of words, it is not clear that the processing of information other than gender interacts with that of semantic information in the N400 time window. We conducted the present study to address these issues.

To examine the processing of case information and lexical relation independently, we used two tasks in the present study: a phrase task and lexical task. The former required participants to judge whether the case which a verb requires was the same as the case of its object while the latter required participants to judge whether the verb and object were lexically related. Note that the phrase task requires retrieving the case which the verbs assign to their objects. By examining the processing of case information and lexical relation independently, we expect both ERP components which reflects the processing of case information and those which reflects the processing of lexical relation to be observed. We crossed the condition of case information (correct vs. incorrect) and the condition of lexical relation (correct vs. incorrect), resulting in the four condition. In this way, we can investigate the interaction between the processing of case information and lexical relation (i.e. whether the processing of case information is affected by lexical relation or vice versa).

In this study, we regard case violations between noun phrases and verbs as phrasal anomalies, which can be considered to be syntactic in that case violations result in the disruption of case assignment to objects. However, this type of case violation is neither word category nor morphosyntactic violations since wo- and ni- verbs belong to the category of verb and they do not have distinct morphological features. This indicates that the case violations in this study may be different from syntactic violations in the previous studies.

In most of the previous studies which used syntactically and semantically anomalous words as critical words, syntactic violations were realized between words placed in more distant positions within a sentence than semantic violations or vice versa. (for a review, see Martín-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006). Martín-Loeches et al. (2006) suggested that both types of violation should be realized by changing words on which the same preceding word puts syntactic or semantic constraints in a sentence because the difference of distance between words can lead to difference in working memory demands, which affects the interaction of syntax and semantics. In the present study, as both phrasal and lexical anomalies are realized between the first and second phrase of the test sentences, this problem can be avoided.

Previous studies reported that the extension of inter-stimulus interval (ISI) facilitates predictive processing of linguistic stimuli (Chow, Lau, Wang, & Phillips, 2018; Momma, 2016; Wlotko & Federmeier, 2015; Yano, 2018). Given these reports, we adopt two types of interstimulus interval (ISI) between noun phrases and verbs: 100 and 500 ms. Since the first phrases of our test sentences consists of nouns and case markers, participants may predict specific types of verb (i.e. wo-verbs or ni-verbs). If the prediction helps the parser to process case information and lexical relation more easily, the ERP component elicited by anomalies will be attenuated. On the other hand, the prediction may enable the parser to detect the anomalies more explicitly. In this case, the ERP component which reflects the detection of anomalies will be larger in the ISI 500 ms condition than in the ISI 100 ms condition.

In the present study, we address the question how case information and lexical relation between noun phrases and verbs are processed in the brain. We expect that if the processing of case information and lexical relation is independent of each other, the ERP components elicited by one type of violation will not be affected by the other type of violation. On the other hand, if the two processing systems interact with each other, the ERP components related to case violations will be altered by lexical anomalies or vice versa. In addition, if the extension of the ISI leads to the predictive processing of the linguistic stimuli, the ERP components which reflects the processing of anomalies will be larger or smaller when the ISI is 500 ms than when the ISI is 100 ms depending on the hypotheses above.

Chapter 2 Methods

2.1 Participants

Thirty-seven undergraduate or graduate students of Tokyo Metropolitan University (20 females, mean age = 20.5, SD = 1.9) participated in the experiment. All the participants were native speakers of Japanese, were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971), and had normal or corrected-to-normal vision. None of them had neurological disorders. This experiment was approved by the Human Subject Ethics Committee of Tokyo Metropolitan University. The participants were paid for their participation.

The data from six participants were not included in the analysis. The exclusion criteria were that the participant correctly answered less than 80% of all judgment tasks and that more than 30% of all the trials were contaminated with artifacts.

2.2 Materials

As for test sentences, we selected 56 ni-verbs and 56 wo-verbs from Goi-taikei: a Japanese lexicon (Ikehara et al., 1999). The number of moras and the degree of lexical familiarity were not significantly different between the two types of verbs (moras: $t(110) = 0.55$, n.s., familiarity: $t(110) = 0.92$, n.s.) according to Nihongo-no Goitokusei: lexical properties of Japanese (Amano & Kondo, 2000). Each verb was combined with a noun phrase consisting of a noun and a case particle ("wo" or "ni") so that they form a two-word sentence. Note that subjects can be omitted in Japanese; these two-word sentences do not have explicit subjects (e.g. "I" or "she" in English). Four types of sentences were created for each two-word sentence: (1) lexically and phrasally correct (LC-PC) sentences; (2) lexically incorrect and phrasally correct (LI-PC) sentences; (3) lexically correct and phrasally incorrect (LC-PI) sentences; and (4) lexically and phrasally incorrect (LI-PI) sentences. The examples for each type of sentence were shown below. “Kangaeru” is a wo-verb and “somuku” is a ni-verb. Literal translations of the phrases are shown in parentheses.

(1) Sakusen wo kangaeru. (plan a strategy: LC-PC sentences)
    Kitai ni somuku. (go against expectations: LC-PC sentences)
(2) Keshigomu wo kangaeru. (plan an eraser: LI-PC sentences)
    Hoken ni somuku. (go against insurance: LI-PC sentences)
(3) Sakusen ni kangaeru. (plan a strategy: LC-PI sentences)
    Kitai wo somuku. (go against expectations: LC-PI sentences)
(4) Keshigomu ni kangaeru. (plan an eraser: LI-PI sentences)
    Hoken wo somuku. (go against insurance: LI-PI sentences)

Sentences were lexically incorrect when nouns and verbs were not lexically related (2 and 4). Sentences were phrasally incorrect when case particles of noun phrases did not match the case which verbs required (3 and 4). In total, 448 sentences were constructed.

In addition, 112 filler sentences were created. The filler sentences were composed of either noun phrases and intransitive verbs or noun phrases and nouns. The noun phrases consisted of nouns and case particles (“ga” or “no”). The case particle “ga” marks the nominative case, which means that a noun phrase marked with “ga” generally acts as a subject in the sentence. On the other hand, the case particle “no” marks the genitive case and a noun phrase marked with “no” generally modifies the following noun phrase. Two types of case particles and two types of words following nouns resulted in four types of sentences (or phrases): (1) a noun + “ga” + an intransitive verb; (2) a noun + “no” + a noun; (3) a noun + “no” + an intransitive verb; (4) a noun + “ga” + a noun, the latter half of which (i.e. (3) and (4)) are phrasally incorrect because noun phrases marked with “no” do not modify verbs and noun phrases marked with “ga” do not modify nouns. For each type of sentence, lexically incorrect sentences were created. Thus, filler sentences consisted of eight types of sentences, each of which had 14 sentences.

The 448 test sentences and the 112 filler sentences amounted to 560 sentences. The 560 sentences were distributed among four lists. Each list was used for one of the four experimental conditions (see below). Combinations of the lists and the conditions were counterbalanced so that the four lists were presented the same number of times in each condition.

2.3 Procedure

The participants were seated in a dimly lit room. The monitor (Mitsubishi, RDT235WX) was 90 cm away from participants. The time course for each trial in the experiment is shown in Figure 1. At the beginning of each trial, a fixation was presented for 800 ms, followed by a blank screen for 300 ms. After that, the first phrase was presented for 500 ms, followed by a blank screen whose duration was either 100 or 500 ms based on the condition (interstimulus interval: ISI, see below). The second phrase was presented for 800 ms, followed by a blank screen for 500 ms. After the blank, a response cue was presented for 950 ms. The response cue was either 'bunpou-tekini?' (phrasally correct?) or 'imi-tekini?' (lexically correct?), which was based on the task participants performed. Participants were required to press the button while the response cue remained on the screen. The trial ended with a blank screen for 1000, 1150, 1300 ms and the next trial began. Before the main experiment, participants were instructed that phrase correctness was determined by correspondence between the case required by verbs and the case of objects and that lexical correctness depended on lexical relatedness between the first phrases and the second phrases. Participants performed four practice blocks to get familiar with the procedure. They could take breaks between the blocks in the main experiment.

In each block, participants were required to perform the phrase task or lexical task. In the phrase task, participants judged whether the case required by a verb corresponded to the case of a noun phrase. In the lexical task, they judged whether a noun and a verb were lexically related. When participants think that the sentence is correct, they pressed the left button of the mouse. When they think that the sentence is incorrect, they pressed the right button of the mouse. Participants were instructed to use their right hand (or left hand) to make a response during the first four blocks and use the opposite hand for the remaining four blocks. The order of the hand to use was counterbalanced among participants. Throughout one block, participants performed either the phrase or lexical task, that is, none of the blocks included both judgment tasks.

Two types of judgment tasks and two types of the length of ISI resulted in four experimental conditions for each participant. Each list was divided into two blocks and the whole session consisted of eight blocks. In each block, 70 sentences were presented to participants. The order of the eight blocks was arranged in the way the same ISI condition did not occur in succession and the judgment tasks were changed every two blocks. The order of blocks was counterbalanced among participants.

2.4 EEG recording

Electroencephalogram (EEG) was recorded from 62 Ag/AgCl electrodes mounted in Waveguard cap (ANT neuro, Enschede, The Netherlands). Electrooculogram (EOG) was recorded from the left-upper side of the outer canthus of the left eye and lower-right side of the outer canthus of the right eye. The ground electrode was on AFz. The EEG was sampled at 1,000 Hz and filtered at DC – 250 Hz. The online EEG recording was referenced to the left mastoid, which was re-referenced off-line to the average of the left and right mastoids. Impedances were kept below 10 kΩ. BrainAmp (Brain Products GmbH, Gilching, Germany) and BrainVision Recorder (Brain Products GmbH, Gilching, Germany) were used for the recording.

2.5 EEG data analysis

The EEG data were analyzed with EEGLAB version 14.1.2 (Delorme & Makeig, 2004) and MATLAB 2014b (The MathWorks Inc., Natick, Massachusetts, USA). Trials in which participants made incorrect responses were not used in the analysis. Also, on each electrode, data including artifacts (exceeding ±80μV) was removed. Trials including over

70 μV potential difference between the two EOG electrodes were excluded. When data in 18 electrodes were removed in a trial, the trial was not included in the analysis. In addition, when data in more than 42 trails in a condition (i.e. 30 % of all the trials in a condition) were removed in a single electrode, all the data recorded from the electrode were not included in the analysis. The EEGs were segmented into epochs ranging 200 ms before to 800 ms after the onset of the second phrases. After a 0.1 – 30 Hz bandpass filter was applied, event related potentials were computed using the baseline of 200 ms before the onset of the second phrases.

Statistical analysis was conducted based on an average of seven electrodes in the five regions of the scalp. The regions were left anterior (AF3, F1, F3, F5, FC1, FC3, FC5), right anterior (AF4, F2, F4, F6, FC2, FC4, FC6), midline (Fz, FCz, Cz, CPz, Pz, POz, Oz), left posterior (CP1, CP3, CP5, P1, P3, P5, PO3) and right posterior (CP2, CP4, CP6, P2, P4, P6) region (Figure 2). In each region, mean amplitudes of 31 ms time windows were calculated every millisecond and ANOVA was performed with Task (lexical vs. phrase), Lexical correctness (correct vs. incorrect), Phrase correctness (correct vs. incorrect) as within-subject factors. The Greenhouse – Geisser correction was applied when sphericity assumption was violated.

Within the four experimental conditions, difference waves among the four types of sentences were examined. In the analysis of the difference waves, cluster-based permutation tests were conducted at a significance level of 0.05 (Oostenveld, Fries, Maris, & Schoffelen, 2011). The cluster-based permutation test is one of the effective methods to overcome the multiple comparison problem although it is not appropriate to define the latency of significant differences between experimental conditions based on the test (Sassenhagen & Draschkow, 2019). In order to support the results of cluster-based permutation tests about the onset and offset of the significant differences, we also conducted a statistical analysis using false discovery rate (Benjamini & Hochberg, 1995). We used fdr_bh (Version 2.3.0.0) provided by David Groppe (retrieved from https://jp.mathworks.com/matlabcentral/fileexchange/27418-fdr_bh) for false discovery rate control. The statistical results of the two tests above were generally the same although there were some differences. Below, we report the results of cluster-based permutation tests. For times points in which the results of the two statistical tests were different from one another, the results of both statistical tests are reported.

Chapter 3 Results

3.1 Behavioral data

Table 1 displays the mean accuracy of judgment tasks in the four experimental conditions. The percentages of correct responses were 91.5 % on average, which shows that participants performed the judgment tasks very well. A repeated-measures ANOVA with Task (lexical vs. phrase), ISI (100 ms vs. 500 ms), Lexical correctness (correct vs. incorrect) and Phrase correctness (correct vs. incorrect) as factors revealed main effects of Task ($F(1,30) = 19.5$, $p < 0.001$), Lexical correctness ($F(1,30) = 15.6$, $p < 0.001$), Phrase correctness ($F(1,30) = 12.7$, $p < 0.005$), and interactions of Task × Lexical correctness ($F(1,30) = 48.9$, $p < 0.001$), Task × Phrase correctness ($F(1,30) = 6.9$, $p < 0.05$) and Lexical correctness × Phrase correctness ($F(1,30) = 23.2$, $p < 0.001$). To investigate whether the phrasal correctness of the sentences affected the accuracy of the lexical task, an ANOVA with ISI and Phrase correctness as factors was conducted as a planned comparison between the accuracy of LC-PC sentences and that of LC-PI sentences. The ANOVA yielded a significant effect of Phrase correctness ($F(1,30) = 13.3$, $p < 0.001$). Similar results were observed in the phrase task. Post-hoc comparisons were conducted to examine whether the lexical correctness affected the accuracy of the phrase task. They revealed that in the phrase task under the both ISI condition, participants made significantly more incorrect responses when presented with LI-PC sentences than when presented with LC-PC sentences (ISI 100 ms condition: $F(1,30) = 43.8$, $p < 0.001$; ISI 500 ms condition: $F(1,30) = 29.9$, $p < 0.001$).

These statistical results indicate that the correctness of case information influenced the accuracy of judgments in the lexical task and that lexical relation between the two phrases influenced the accuracy of judgments in the phrase task. Case information and lexical relation in the sentences were processed regardless of the task which participants performed. While judgment tasks required participants to focus on the specific information (i.e. case information or lexical relation) of the sentences, the other information had an influence on the accuracy of the tasks.

3.2 ERP data

3.2.1 Grand average ERPs in the two ISI conditions

Figures 3 and 4 display ERP waveforms elicited by the second phrases in the two ISI conditions. Similar ERP waveforms were observed in the ISI 100 ms and the ISI 500 ms condition. Visual inspection suggests that in both judgment tasks under the ISI 100 ms condition, all the sentences elicited similar negative and positive deflections from around 100 to 200 ms. After these deflections, the ERP waveforms were negatively deflected. In the phrase task, all the sentences except for the LC-PC sentences elicited larger negativities than LC-PC sentences from around 350 ms. After about 350 ms, the LC-PC sentences elicited a positivity whose peak was at around 600 ms. In the lexical task, the LI-PC and LI-PI sentences elicited larger negativities from around 350 ms. The LC-PC and LC-PI sentences elicited positive deflections peaking at about 600 ms. Difference waves among the four types of sentences were statistically analyzed to examine whether lexical and phrasal anomalies had influences on the sentence processing. In the five regions on the scalp mentioned above (see Methods), significant differences among the sentences were most clearly observed in midline. Thus, the difference waves and the results of the analysis in midline are shown below.

3.2.2 Difference waves in the lexical task under the ISI 100 ms condition

Difference waves were calculated to investigate how lexical and phrasal anomalies affected the processing in the brain during the two judgment tasks. Figure 5 displays difference waves among the four types of sentences in the lexical task under the ISI 100 ms condition. The cluster-based permutation test revealed that there were significant differences between LI-PC and LC-PC sentences (Figure 5a) and between LI-PI and LC-PI sentences (Figure 5b). Each cluster extended from 279 and 785 ms and from 325 to 785 ms. These results show that a negativity was elicited by lexical anomalies regardless of whether the case required by verbs corresponded to the case of objects.

A negativity was also elicited when the sentences consisting of two lexically related phrases had case violations. The cluster-based permutation test showed a significant difference between LC-PI and LC-PC sentences (Figure 5c). A cluster spanned approximately from 376 to 521 ms. There were not any significant differences between LI-PI and LI-PC sentences (Figure 5d). Whereas case violations elicited negativities in the sentences consisting of two lexically related phrases, they did not in the sentences where the two phrases were not lexically related.

3.2.3 Difference waves in the phrase task under the ISI 100 ms condition

Figure 6 displays difference waves in the phrase task under the ISI 100 ms condition.

Lexical anomalies elicited negativities even when participants were instructed to focus on the case required by verbs. The cluster-based permutation test revealed a significant difference between LI-PC and LC-PC sentences (Figure 6a). A cluster was formed between 349 and 754 ms. On the other hand, there were not any significant differences between LI-PI and LC-PI sentences (Figure 6b). This indicates that when the sentences had case violations in the phrase task, lexical anomalies did not have an influence on the ERP waveforms.

When the sentences consisted of lexically related phrases, case violations elicited negativities. The cluster-based permutation test revealed a significant difference between LC-PI and LC-PC sentences, corresponding to a cluster spanning from 341 to 769 ms (Figure 6c). On the other hand, there were not any significant differences between LI-PI and LI-PC sentences (Figure 6d). This indicates that the negativity was not elicited by case violations when the two phrases were not lexically related. It was in contrast to the result in the lexical task; while lexical anomalies elicited negativities in the lexical task regardless of whether the case required by verbs corresponded to the case of objects (Figures 5a and 5b), case violations elicited negativities in the phrase task only when the two phrases were lexically related (Figures 6c and 6d).

3.2.4 Differences between the two judgment tasks under the ISI 100 ms condition

As mentioned in the previous sections, negative deflections were not similarly observed between the lexical and phrase task. Lexical anomalies elicited negativities in the lexical task regardless of whether the case assigned to objects by verbs corresponds to the case of objects (Figures 5a and 5b) whereas case violations elicited negativities in the phrase task only when the two phrases were lexically related (Figures 6c and 6d). This was further confirmed by an ANOVA with Task (lexical vs. phrase) and Type of difference wave (LI-PI minus LI-PC vs. LI-PI minus LC-PI) as factors. The ANOVA was conducted every millisecond after the onset of the second phrase. In midline, a significant interaction of Task × Type of differences wave was observed from 337 ms to 770 ms. This interaction reflected that LI-PI sentences elicited more negative deflections than LC-PI sentences in the lexical task while LI-PI sentences did not elicit more negative deflections than LI-PC sentences in the phrase task.

Differences between the two tasks were also observed in the amplitude of negativities elicited by lexical and phrasal anomalies (Figures 5a, 5c, 6a and 6c). An ANOVA with Task and Type of difference wave (LI-PC minus LC-PC vs. LC-PI minus LC-PC) was conducted every millisecond to examine whether difference amplitudes between LI-PC and LC-PC sentences were significantly different from those between LC-PI and LC-PC sentences depending on the type of task. The ANOVA yielded a significant interaction of Task × Type of differences from 130 to 172 ms and from 322 to 785 ms. Figures 7 displays the mean difference amplitudes between the LI-PC or LC-PI sentences and the LC-PC sentences. Between 130 – 172 ms (Figure 7a), a more negative deflection was observed in response to the LI-PC sentences compared to the LC-PI sentences in the lexical task while it was observed in response to the LC-PI sentences compared to the LI-PC sentences in the phrase task. Between 322 – 785 ms (Figure 7b), similar amount of negativity was observed between the LI-PC and LC-PI sentences in the phrase task whereas the LI-PC sentences elicited more negativity than the LC-PI sentences in the lexical task. Although different trends were observed in the two time windows, both data confirms the result of the statistical analysis above (i.e. the significant interaction of Task × Type of differences).

In addition, between 322 – 785 ms, the amplitude of the N400 in response to the lexical anomalies in the lexical task was significantly larger than that in response to case violations in the phrase task ($t(1,30) = 2.2$, $p < 0.05$) although the lexical and phrase task required the processing of lexical relation and case information, respectively.

3.2.5 Difference waves in the lexical task under the ISI 500 ms condition

Figure 8 shows differences waves in the lexical task under the ISI 500 ms condition. The results were similar to those in the lexical task under the ISI 100 ms condition. The cluster-based permutation test showed that there was a significant difference between LI-PC and LC-PC sentences (Figure 8a). A cluster extended from 309 to 785 ms. There was also a significant difference between LI-PI and LC-PI sentences (Figure 8b). Three clusters were formed from 94 to 202 ms, from 361 to 542 ms and from 622 to 785 ms. These results show that negativities were elicited by lexical anomalies regardless of whether the case required by verbs corresponded to the case of objects. However, the ISI 500 ms condition differed from the ISI 100 ms condition in the following points: (1) The difference wave between LI-PI and LC-PI sentences were smaller. (2) One cluster in early latency indicated LI-PI sentences elicited a more positive deflection than LC-PI sentences from 94 to 202 ms.

There was a significant difference between LC-PI and LC-PC sentences, corresponding a cluster from 281 and 638 ms (Figure 8c). Case violations elicited negative deflections as in the lexical task under the ISI 100 ms condition. No significant differences were observed between LI-PI and LI-PC sentences (Figure 8d). When the two phrases of sentences are not lexically related, case violations did not affect the ERP waveforms.

3.2.6 Difference waves in the phrase task under the ISI 500 ms condition

Figure 9 shows difference waves in the phrase task under the ISI 500 ms condition. The results were similar to those in the phrase task under the ISI 100 ms condition. The cluster-based permutation test showed a significant difference between LI-PC and LC-PC sentences (Figure 9a). A cluster was formed from 339 to 754 ms. A statistical analysis using false discovery rate revealed a significant difference from 121 to 160 ms between the two sentences, which was not found in the cluster-based permutation test (a blue line in Figure 9a). Thus, lexical anomalies elicited a positivity in an early time window and a negativity in a later time window. A significant difference was also found between LI-PI and LC-PI sentences. A cluster spanned from 419 to 507 ms (Figure 9b). Lexical anomalies elicited negativities regardless of whether the case required by verbs corresponded to the case of objects, which was different from the result in the ISI 100 ms condition.

The cluster-based permutation test revealed a significant difference between LC-PI and LC-PC sentences (Figure 9c). A cluster extended from 389 to 755 ms. On the other hand, no significant differences were found between LI-PI and LI-PC sentences (Figure 9d). These results were the same as in the phrase task under ISI 100 ms condition. Even when participants focused on the case required by verbs, case violations in the lexically anomalous sentences did not elicit negative deflections.

3.2.7 Differences between the two judgment tasks under the ISI 500 ms condition

In the ISI 500 ms condition, case violations did not elicit negativities in the phrase task when the two phrases were not lexically related (Figure 9d). This was also observed in the phrase task under the ISI 100 ms condition (Figure 6d). However, in the lexical task under the 500 ms condition, the amplitude differences between LI-PI and LC-PI sentences were small compared to those in the lexical task under the ISI 100 ms condition (Figures 5b and 8b). An ANOVA with Task and Type of difference wave as factors was carried out to examine whether there were significant amplitude differences between the lexical and phrase task as in the ISI 100 ms condition. The ANOVA only revealed a significant interaction of Task × Type of difference wave from 647 to 770 ms. The range of time periods in which the significant interaction was observed was narrower than that in the ISI 100 ms condition. Thus, although amplitude differences between LI-PI and LC-PI sentences in the lexical task was significantly more negative than those between LI-PI and LI-PC sentences in the phrase task (Figures 8b and 9d), the differences between the two tasks were smaller than those in the ISI 100 ms condition.

Differences between the two tasks were less observed in the amplitude of negativities elicited by lexical and phrasal anomalies (Figures 8a, 8c, 9a and 9c). To test whether amplitude differences between LI-PC and LC-PC sentences were significantly different from those between LC-PI and LC-PC sentences depending on the task as in the ISI 100 ms condition, an ANOVA with Task and Type of difference wave (LI-PC minus LC-PC vs. LC-PI minus LC-PC) was carried out. The ANOVA yielded a significant interaction of Task × Type of differences from 632 to 785 ms. It indicates that difference amplitudes between LI-PC and LC-PC sentences were significantly more negative than those between LC-PI and LC-PC sentences in the lexical task whereas they were not in the phrase task. It is also clear from Figure 10, which displays the difference amplitudes between LI-PC or LC-PI sentences and the LC-PC sentences in this time window. The difference between the tasks in the ISI 500 ms condition was smaller than that in the ISI 100 ms condition since the interaction was observed in a narrower time range.

There was another difference between the lexical and phrase tasks. LI-PI sentences in the phrase task elicited a significantly more negative deflection than LC-PI sentences while LI-PI sentences in the lexical task did not elicit a more negative deflection than LI-PC sentences (Figures 8d and 9b). This difference was not observed in the ISI 100 ms condition.

3.2.8 Similarities and differences between the two ISI conditions

Figure 11 displays the result of ANOVAs for five regions of the scalp in the two ISI conditions. The main effect of Phrase correctness and the interaction of Lexical correctness × Phrase correctness were similarly observed in both ISI conditions. The former was observed about from 360 ms to 730 ms; the latter was mostly observed about from 400 ms to 700 ms.

There were three major differences between the two ISI conditions. First, a significant effect of Task was observed in all the five regions in the ISI 100 ms condition while it was not observed in the ISI 500 ms condition. Second, significant interactions of Task × Lexical correctness and Task × Phrase correctness were clearly observed in the ISI 100 ms condition but not in the ISI 500 ms condition. Third, a significant effect of Lexical correctness was observed in different time periods. In the ISI 100 ms condition, the effect was significant from about 210 ms in the five regions. In the ISI 500 ms condition, it was significant during earlier time points (about 100 – 150 ms) in the four regions. Effects of the task were less observed in the ISI 500 ms condition than in the ISI 100 ms condition. On the other hand, the significant effect of Lexical correctness was observed earlier in ISI 500 ms condition than in the ISI 100 ms condition.

Chapter 4 Discussion

This study investigated how case information and lexical relation in two-word sentences (consisting of noun phrases and verbs) are processed in Japanese by adopting the phrase and lexical task. The results of the study are summarized in the three points. Firstly, lexical anomalies elicited a negativity around 400 ms after the onset of the second phrase in the lexical task while case violations elicited a negativity in a similar time window in the phrase task. This indicates that the processing of case information and lexical relation is reflected in the similar type of brain activity. Secondly, lexical anomalies elicited a negativity in the lexical task regardless of whether the case required by verbs was the same as that of objects whereas case violations elicited a negativity in the phrase task only when the two phrases (i.e. noun phrases and verbs) were lexically related. This suggests that in the phrase task, lexical relation between the phrases affected the processing of case information. Finally, when the ISI was extended from 100 ms to 500 ms, the main effect of Task was not observed. It suggests that in the phrase task under the ISI 500 ms condition, case violations were processed with less effort than in the phrase task under ISI 100 ms condition. Consequently, lexical information may have been deeply processed and a significantly larger negativity was elicited when sentences include lexical and case anomalies than when sentences only include case anomalies. Below, we discuss these points in detail.

4.1 The N400 elicited by lexical anomalies and case violations

Lexical anomalies elicited a negativity about 400 ms post-stimulus onset. Considering its latency and broad distribution over the scalp (Figures 3 and 4), we interpret the negativity as an N400. As we mentioned in Introduction, there are two views about the functional interpretation of the N400. Although it is beyond the scope of this paper to determine which process was reflected in the N400 of this study, the fact that the N400 was elicited by lexically unrelated words is consistent with both views of the N400.

Case violations also elicited a negativity which peaked around 400 ms. We consider this negativity as an N400 since it was broadly distributed over the scalp as in lexical anomalies (Figures 3 and 4). We propose that this negativity reflected the inconsistency of case between noun phrases and verbs, and that the case violation was detected when the parser accessed the lexical information of the verbs. Since verbs were presented after noun phrases, whether a noun phrase and a verb form a correct phrase was determined by the case which the verb requires. Researchers of Japanese case markers suggests that verbs contain the information about what type of thematic role and case they assign to noun phrases in their lexical entries (Ishiwata, 1999; Muraki, 2000). Given this proposal, we consider that the parser identified the case which the verb requires (i.e. “wo” or “ni”) when it accessed the lexical information of the verb, and that the inconsistency of the case between the noun phrase and the verb resulted in the elicitation of an N400. This view is in line with Kobayashi et al. (2007), which reported an N400 elicited by the same type of case violation as the one used in this study. The observation of the N400 also confirms that case violations in the present study are different from syntactic violations used in the previous studies (e.g. word category or morphosyntactic violations). As pointed by Friederici & Weissenborn (2007), when syntactic violations are realized by manipulating information in the lexical entry (e.g. gender disagreement), they may be not syntactic in nature (i.e. they are not independent from lexical semantics).

Although both case violations and lexical anomalies elicited the N400, different amplitudes of the N400 were observed in response to these anomalies depending on the tasks. In the lexical task, lexical anomalies elicited a larger negativity than case violations (Figures 7b and 10). We consider that this is because the task required focusing on lexical relation between nouns and verbs. On the other hand, in the phrase task, case violations and lexical anomalies elicited a similar amplitude of the N400. Since the phrase task required participants to focus on case information, case violations would have elicited a larger negativity than lexical anomalies if the processing of two anomalies was reflected in the similar amount of brain activity. This was not the case; case violations in the phrase task under the ISI 100 ms condition elicited a significantly smaller amplitude of the N400 compared to lexical anomalies in the lexical task under the ISI 100 ms condition (Figure 7b). It suggests that lexical anomalies elicit a larger N400 than case violations. As lexical anomalies and case violations are different types of violation, this quantitative difference in the amplitude of the N400 suggests not only that the different amount of neural activity was engaged in the two processes (one for case violations and the other for lexical anomalies), but also that the two types of anomalies were differently processed in the brain. That is, even reflected in the same component, the two processes are operated by qualitatively different brain activities.

The amplitude differences of the N400 between case violations and lexical anomalies are explained as follows. Case violations were detected when a noun phrase had a case marker “ni” and a verb required a case marker “wo” and vice versa. Once case violation is detected, an N400 is elicited. The correct case is easily retrieved by the parser because there are only two types of case markers in this study; when one is incorrect, the other is correct. Consequently, the parser will find the correct case with little effort. However, the extra amount of processing will be required in lexical anomalies because judging whether two words are lexically related is a gradual rather than a dichotomous process. In this way, the extra processing required for the judgment of lexical relatedness will lead to a larger amplitude of the N400.

The N400 elicited by case violations and lexical anomalies was not task-dependent. That is, this ERP component was observed both when case violations occurred in the lexical task and when lexical anomalies occurred in the phrase task. This observation suggests that case information and lexical relation were both processed in the two tasks. The parallel processing of syntax and semantics was assumed in phase 2 of the model proposed by Friederici (2002) (see also Friederici & Weissenborn, 2007). In this phase, morphological violations are reflected by the LAN and semantic violations are reflected by the N400. Different from this proposal is that in this study the parallel processing was reflected in the same ERP component, i.e. the N400. Although this result suggests that case information and lexical relation were processed in a similar time sequence, we have to be cautious about the temporal characteristics of the ERP components; the onset of the effects should not be regarded as the exact time point in which brain activity begins to differ between experimental conditions (Otten & Rugg, 2005).

In the lexical task, lexical anomalies elicited a negativity regardless of whether the sentences included case violations (Figures 5a, 5b, 8a and 8b). This is because the task required participants to focus on lexical relation between nouns and verbs. Even when sentences included case violations, the parser was able to detect lexical anomalies. From this result, it was expected that case violations elicited a negativity regardless of lexical relation between the two words; however, the result in the phrase task indicates that neural activity was not differentiated by additional case violations when the two words were not lexically related (Figures 6d and 9d). It suggests that lexical semantics was predominantly processed in the brain. One important question arises; why was lexical semantics processed predominantly when participants were required to check the consistency of case?

We argue that this is because case marking is intricately related to lexical relation between noun phrases and verbs. Verbs require noun phrases as arguments and give them specific thematic roles. These noun phrases have to meet the semantic requirement of verbs; that is, noun phrases cannot be arguments of verbs unless they match the events expressed by meaning of verbs. Certain case markers related to the thematic roles are attached to these noun phrases. In other words, unless noun phrases have suitable thematic roles for the event expressed by meaning of verbs, proper case markers cannot be attached to the noun phrases. In the case of this study, “wo” or “ni” is attached to nouns when the nouns act as objects for the events represented by verbs. For the parser to identify the correct case marker of noun phrases, thematic roles of the noun phrases must be clarified. Since thematic roles are given to noun phrases which meet the semantic requirement of verbs, lexical relation between noun phrases and verbs must be checked. We argue that this is why lexical semantics was predominantly processed in the phrase task. The assignment of case markers is inseparable from lexical relation between noun phrases and verbs since the meaning of noun phrases and verbs is deeply related to thematic assignment.

In the sense that the processing of case information requires the checking of lexical relation between noun phrases and verbs, this suggests that the processing of case information was interacted with that of lexical relation. This interaction is similar to that observed in Hagoort (2003) and Wicha et al. (2004) in that the processing of one type of information interacted with that of the other type of information in the N400 time window. In these studies, violations of gender information encoded in the lexical entry of words increased the amplitude of the N400 which was elicited by semantic violations. The results of Hagoort (2003), Wicha et al. (2004) and the present study shows that when two types of information encoded in words are processed, the interaction between the processing of one type of information and that of another type of information occurs at the N400 time window. This type of interaction occurs earlier than the interaction between syntax and semantics in a sentence which occurs at the P600 time window.

The interaction between the processing of case information and lexical relation is reflected in the behavioral data of the present study. Although each task required participants to focus on case information or lexical relation, the information which participants did not pay attention to influenced the accuracy of the task. Lexical anomalies lowered the accuracy in the phrase task while case violations lowered the accuracy in the lexical task (Table 1).

Previous studies using double violation paradigm reported significant main effects of semantic and syntactic correctness in behavioral data (Martín-Loeches et al., 2006; Ye, Luo, Friederici, & Zhou, 2006; Zhang, Yu, & Boland, 2010). In these studies, the accuracy of the acceptability (or overall correctness) judgment in correct sentences was significantly lower than that in semantically or syntactically incorrect sentences. This trend is the opposite to the result of the present study, in which the accuracy for the LC-PI sentences was significantly lower than that for LC-PC sentences in the lexical task and the accuracy for the LI-PC sentences was significantly lower than that for LC-PC sentences in the phrase task. This is due to the specific nature of the material and task in this study.

The present study used two-word sentences, the length of which was shorter than the sentences used in the previous studies. Since the critical sentences were short, it was easy for participants to judge the correctness of them. On the other hand, in the previous double violation studies, participants had to fully process the content of the critical sentences in order to judge them to be correct. This may be the reason why the accuracy for the correct sentences was lower than that for sentences with violations.

In the acceptability judgment, no additional processing is necessary once the parser detects the incorrectness. This would raise the accuracy of incorrect sentences. In contrast, both of the judgment tasks in the present study required further processing. When LC-PC or LI-PI sentences were presented, case information and lexical relation were either correct or incorrect. There was no conflict in making correct responses in the judgement tasks. When the LI-PC or LC-PI sentences were presented, however, performing each task requires participants to ignore the correctness (or incorrectness) of case information or lexical relation. For example, when presented with the LI-PC sentences in the phrase task, participants had to respond “correct” ignoring the incorrectness of case. This may have resulted in a situation where participants were influenced by the lexical or phrasal information they did not attend to. We suggest that these differences resulted in the inconsistency between the behavioral data in the previous studies and those in the present study.

Since the ERP components elicited in response to case violations were similar to those elicited in response to lexical anomalies in that both of the ERP components were observed in the same polarity and similar time window, the processing of case information and lexical relation may share the resources for language processing. If the resources are shared by both types of processing, lack of amplitude difference between LI-PI and LI-PC sentences in the phrase task under the ISI 100 ms condition can be explained as follows: most of the resources were used for the processing of lexical anomalies and as a result, the processing of case information did not occur due to the insufficient resources. However, as we discussed above, the results of the present study suggest that lexical relation between verbs and objects needs to be checked for the parser to determine the correct case to be assigned by the verbs to the objects. In other words, the processing of case information is not likely to occur when the preceding noun phrases do not act as objects for verbs; this is because the parser is not able to determine the proper case to be assigned to the objects.

In LI-PI sentences, lexical relation was checked before the processing of case information because the processing of lexical relation was necessary for the parser to recognize the preceding noun phrases as objects for verbs. When lexical anomalies were detected, the parser was not able to determine the correct case, which resulted in the absence of the processing of case information. In this case, whether the processing of case information and lexical relation shares the resources or not, case information may not be processed when lexical anomalies are detected. Thus, the results of the present study do not necessarily indicate that the processing of case information and lexical relation share the resources for language processing.

One may argue that case violations caused problems in thematic assignment. Sakamoto (2015) mentioned that accusative-marked noun phrases tended to be associated with the thematic role of Patient and dative-marked noun phrases tended to be associated with the thematic role of Goal. When the case of a noun phrase is altered, the case and thematic role of the noun phrase do not meet the requirements of an upcoming verb. He claimed that this conflict would result in the N400. However, Bornkessel et al. (2003) argued that specific thematic roles (e.g. Agent) were unlikely to be assigned before the parser processed verbs because information of the exact thematic roles assigned to noun phrases was only provided by verbs. Their proposal is compatible with the studies of Japanese case markers (Ishiwata, 1999; Muraki, 2000), which suggest that each case marker does not necessarily correspond to the specific meaning (or thematic role). Hence, it is unlikely that problems in thematic assignment occurred due to case violations.

4.2 ERP components and their eliciting conditions

4.2.1 The LAN and predictive processing

Researchers reported a LAN in response to the sentences with case violations (Arao et al., 2007; Coulson et al., 1998; Friederici & Frisch, 2000; Yano, 2018); however, the LAN was not observed in the present study. By examining the differences between the previous studies and the present study, we discuss what circumstances lead to the elicitation of the LAN or the N400.

First of all, there are not any morphological distinctions between wo- and ni-verbs. As the LAN is proposed to reflect the error of morphological prediction (Molinaro et al., 2011), this ERP component was unlikely to be observed in the present study. This point is related to the difference between Coulson et al. (1998) and the present study. Coulson et al. (1998) observed a LAN when participants were presented with sentences in which a word marked with the accusative or genitive (or possessive) case following a verb was changed to the one with the nominative case. As languages like English has fixed word orders, it is highly predictable that a noun following a verb is marked as the accusative or genitive case. Under the circumstances in which the case of incoming words is predictable from word order information, a LAN is elicited by case violations (see Kobayashi et al., 2007 for similar arguments).

Adopting the same type of case violation as the one used in our study, Arao et al. (2007) observed a LAN. The authors required participants to perform grammatical judgments during the experiment. In addition, when presented with grammatically incorrect sentences, the participants were required to internally reproduce the correct sentences (i.e. without making explicit responses) by fixing the incorrect case marker to the correct one. This correction process may have induced the participants to focus on case markers and actively predict whether the upcoming verb matches the case marker presented. Consequently, a LAN was elicited when the prediction of upcoming verbs was violated.

Yano (2018) also reported a LAN. He claimed that the LAN reflected the error of structural prediction. In his study, the test sentences consisted of inanimate noun phrases and intransitive verbs and case violations were realized by changing a case marker "ga" which marks the nominative case to "wo" which marks the accusative case. He claimed that when presented with an inanimate noun phrase with an accusative case marker "wo", participants predicted the upcoming verb would be transitive because the thematic roles of Theme were likely to be assigned to inanimate noun phrases. This structural prediction was violated as intransitive verbs were presented to participants, which resulted in the observation of the LAN. His proposal is supported by the results of Coulson et al. (1998) and Arao et al. (2007). As we mentioned above, these studies suggest that a LAN is elicited when the structural prediction of upcoming words is violated.

Nonetheless, the results of Yano (2018) are not directly compared with those of the present study. The test sentences in his study included violations of transitivity in addition to case violations. As accusative-marked noun phrases cannot be assigned thematic roles by intransitive verbs, transitivity violation causes problems in thematic assignment, which elicits the N400 (Friederici & Frisch, 2000; Frisch et al., 2004). Although both being referred as case violations, switching a case marker "wo" to "ni" or vice versa is different from switching a case marker "ga" to "wo" because the case violation occurs between objects and verbs in the former while it does between subjects and verbs in the latter.

Friederici & Frisch (2000) reported a LAN using similar type of case violation as the one in our study. If information as to which case verbs require is encoded in the lexical entry of the verbs as in Japanese, their critical sentences would have elicited an N400 because in their study case violations were realized by changing the dative case of the second phrase to the accusative case. The result of their study suggests the possibility that information as to the case which verbs require is represented in a different manner.

The present study is different from the previous studies in that participants may not have predicted upcoming words. It was not predictable from syntactic structure whether a verb required “wo” or “ni”. The lexical and phrase task did not require participants to actively predict the type of upcoming verb. We suggest that the predictive process in syntactic structure is a crucial factor in the elicitation of the LAN (see Molinaro et al., 2011 for similar arguments) and that this is the reason the LAN was not observed in the present study.

4.2.2 The P600 and length of the test sentences

In contrast to Kobayashi et al. (2007), we did not observe a P600 in sentences with case violations. Instead, we observed a positive deflection around 600 ms post-stimulus onset in correct sentences. This result is the opposite to the previous studies which reported positive deflection around 600 ms (P600) in grammatically incorrect (Hagoort, Brown, & Groothusen, 1993; Hahne & Friederici, 1999), structurally unpreferred (Osterhout & Holcomb, 1992; Osterhout, Holcomb, & Swinney, 1994), or semantically implausible

(Chow & Phillips, 2013; Hoeks, Stowe, & Doedens, 2004; Kim & Osterhout, 2005; Van Herten, Kolk, & Chwilla, 2005) sentences. We speculate that this is due to the length of the test sentences. Presenting participants with three word sentences (a noun phrase marked with the nominative case + a noun phrase marked with the accusative case + a verb), Arao et al. (2007) also observed a positive deflection around 600 ms post-stimulus onset not in violated sentences but in correct sentences. In their study, case violations were realized by changing the case marker of the second phrase. Since the first phrase was not related to the correctness of the test sentence, participants could perform the grammatical judgment only focusing on the case marker attached to the second word and the case required by the verb. This may have resulted in a situation where only two-word phrases were processed. In fact, the ERP waveforms in Arao et al. (2007) were similar to the waveforms reported in Münte, Heinze, & Mangun (1993). Münte et al. (1993) presented participants with two-word phrases which consisted of nouns and verbs and required them to judge the grammatical correctness of the phrases. Since Münte et al. (1993), Arao et al. (2007) and the present study observed positive deflections around 600 ms in the correct sentences, it may be the case that the processing of two-word sequences was different from the processing of more than three word sequences. In fact, effects of the preceding context is proposed to be a factor of the elicitation of the P600 (Kuperberg, 2007; Kuperberg, Kreher, Sitnikova, Caplan, & Holcomb, 2007). Thus, the absence of the P600 in the incorrect sentences and the observation of the positive deflection in the correct sentences may be due to the length of the critical sentences.

4.3 The effect of ISI on processing of two-word sentences

When the ISI was extended to 500 ms, the main effect of Task was not observed. This is due to the significant difference between LI-PI and LC-PI sentences in the phrase task under the ISI 500 ms condition, which was not observed in phrase task under the ISI 100 ms condition. Except for this difference, similar results were found in the both ISI conditions.

We propose that extension of the ISI led to deeper (or additional) processing of noun phrases in the phrase task. Due to that, the parser could have processed the case information of verbs more effortlessly than in the ISI 100 ms condition. In addition, the longer ISI may also have enabled the parser to deeply process lexical relation between noun phrases and verbs. As a result, the lexical anomaly in the LI-PI sentences elicited an N400.

4.4 Limitations of the present study

Although we investigated the interaction between the processing of case information and lexical relation in the N400 time window, previous studies have shown the interaction of syntax and semantics in the P600 time window (Gunter et al., 2000, 1997; Wicha et al., 2004). In this study, the late interaction between the processing of case information and lexical relation was not examined since the incorrect sentences did not show a P600 in contrast to the previous studies. Future studies need to clarify the interaction observed in this study will extend to the later time window.

In addition, it also needs to be examined whether the processing of case information shows the interaction with lexical relation in different circumstances. Although noun phrases to which the case is assigned by wo- and ni-verbs act as objects, these noun phrases bear different case markers depending on the type of verb. The processing of case information in both types of verbs requires the parser to access the information about which case the verbs require and to check whether the preceding case marker is appropriate given that information. This process may not be necessary in case assignment between subject and verbs. Subjects are generally marked with the case marker “ga” in Japanese. Since whether noun phrases can act as subjects in sentences is not determined by the case assignment by verbs, the information about the nominative case may not be encoded in the lexical entry of verbs. Given that case assignment between subjects and verbs occurs without access to the information in the lexical entry of verbs, the processing of case information can be regarded more syntactic. It needs to be examined whether the interaction between the processing of case information and lexical relation is observed or not in the sentences composed of subjects and verbs.

To investigate the processing of case information and lexical relation between verbs and objects, The present study used two-word sentences as stimuli. Since the test sentences lacks subjects, which cannot be omitted in languages like English, different results may be obtained in the sentences including subjects. Further studies are needed to clarify that the interaction between the processing of case information and lexical relation also occurs in three-word sentences.

Conclusion

The present study investigated how case information and lexical relation between verbs and objects are processed in the brain. The results demonstrated the two points: (1) Case violations elicit the N400. (2) The processing of case information is not independent of that of lexical relation. Although interaction of syntax and semantics was assumed in the P600 time window (Friederici, 2002; Friederici & Weissenborn, 2007), this study suggests that the interaction between the processing of case information and lexical relation between verbs and objects occurs in an earlier time window. Further investigation is required to clarify in what circumstances the interaction between the processing of case information and lexical relation occurs.

Figures and tables

Experimental conditions	Four types of the sentences			
	LC-PC sentences	LI-PC sentences	LC-PI sentences	LI-PI sentences
ISI 100 ms Phrase task	95.7 (5.2)	88.9 (8.5)	90.1 (7.6)	84.9 (7.4)
ISI 500 ms Phrase task	96.0 (4.3)	87.3 (6.4)	90.8 (5.7)	86.5 (7.4)
ISI 100 ms Lexical task	93.9 (6.7)	92.9 (7.9)	89.5 (7.8)	95.5 (3.7)
ISI 500 ms Lexical task	94.6 (5.2)	91.7 (6.4)	91.2 (5.6)	94.0 (5.0)

Table 1. Mean accuracy of judgment tasks in the four experimental condition. LC-PC sentences: lexically and phrasally correct sentences, LI-PC sentences: lexically incorrect and phrasally correct sentences, LC-PI sentences: lexically correct and phrasally incorrect sentences, LI-PI sentences: lexically and phrasally incorrect sentences. ISI: interstimulus interval, SDs are given in parentheses.

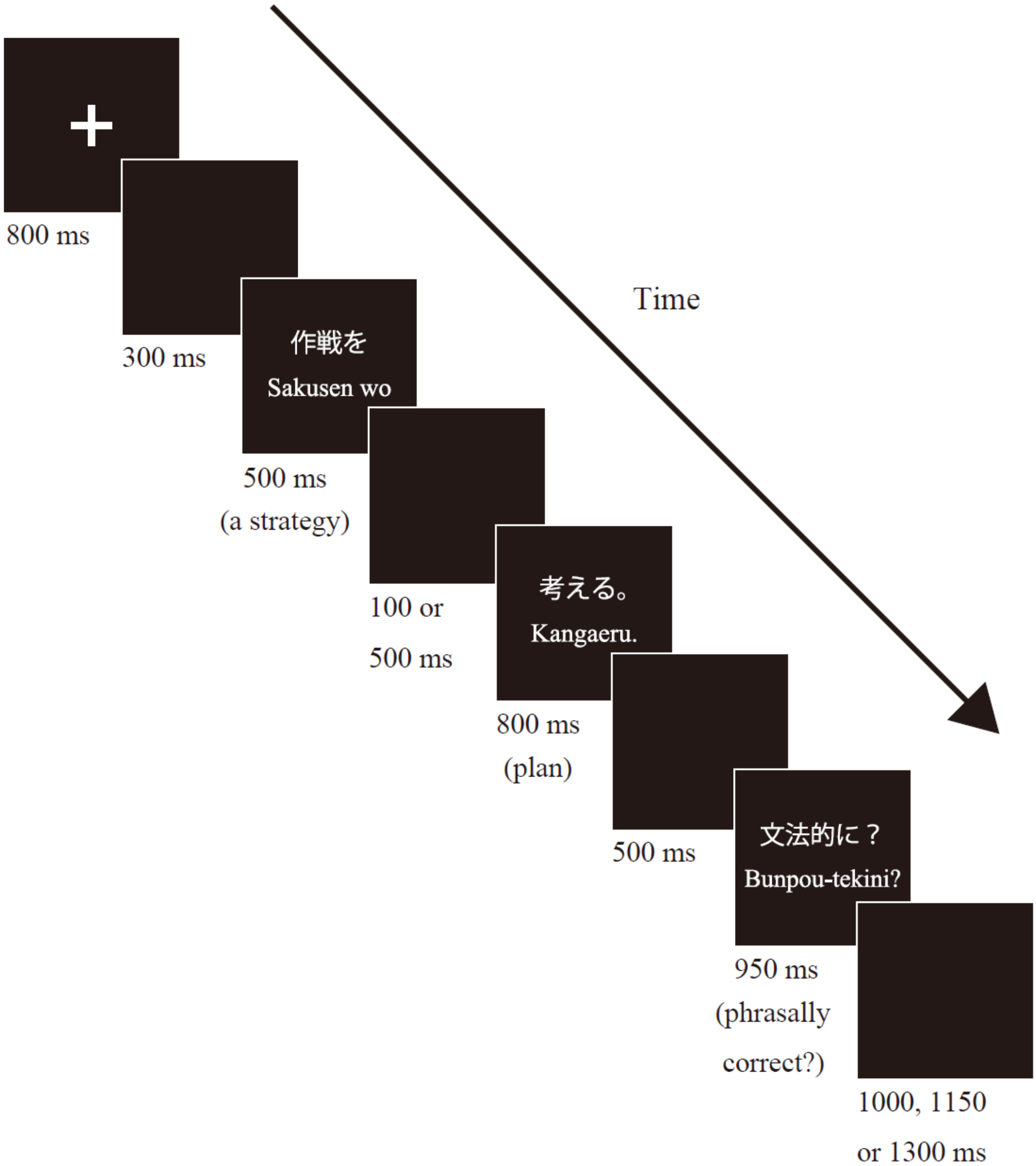

Figure 1. Time course for each trial in the experiment. Numbers on the lower-left side of the black squares indicate the duration during which the stimuli on a black background were presented with participants. Literal translations of the stimuli are shown in parentheses below the duration. The stimulus presentation proceeded from left-upper side to lower-right side. Note that the basis word order in Japanese is SOV.

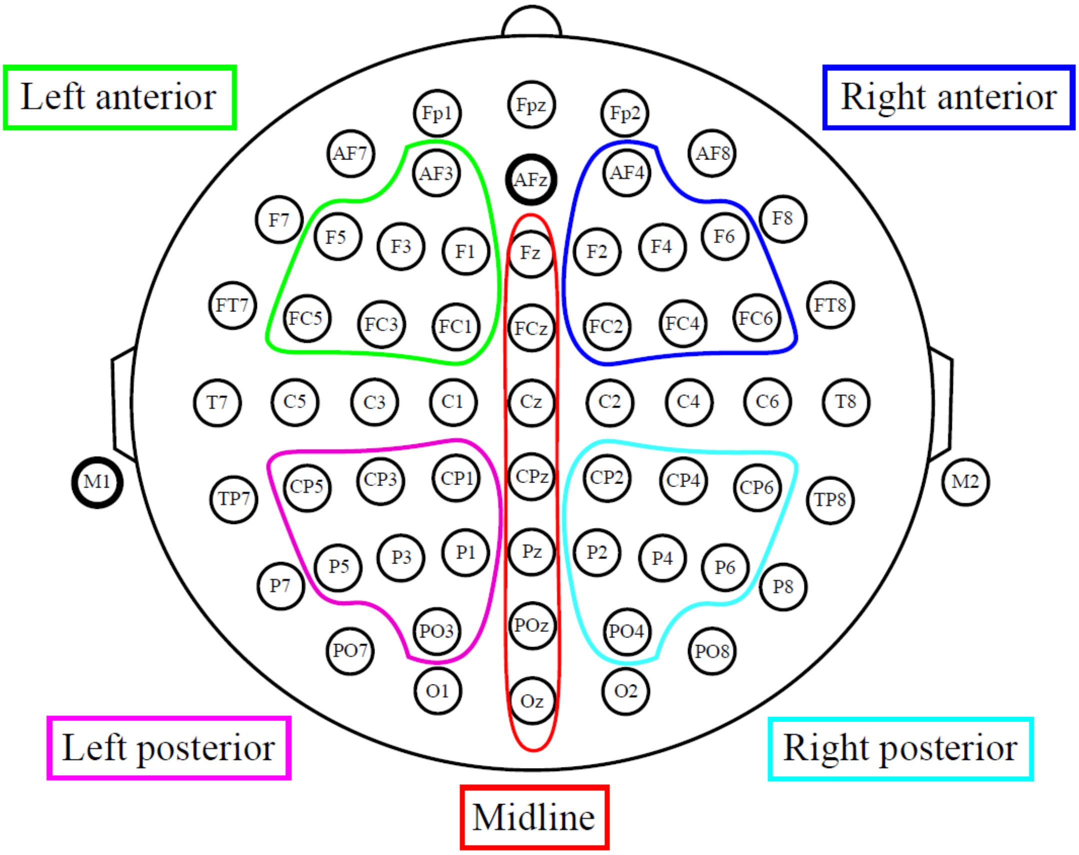

Figure 2. Electrode positions in the experiment. Five regions used for the analysis are shown. AFz and M1 served as the ground electrode and the reference electrode, repectively.

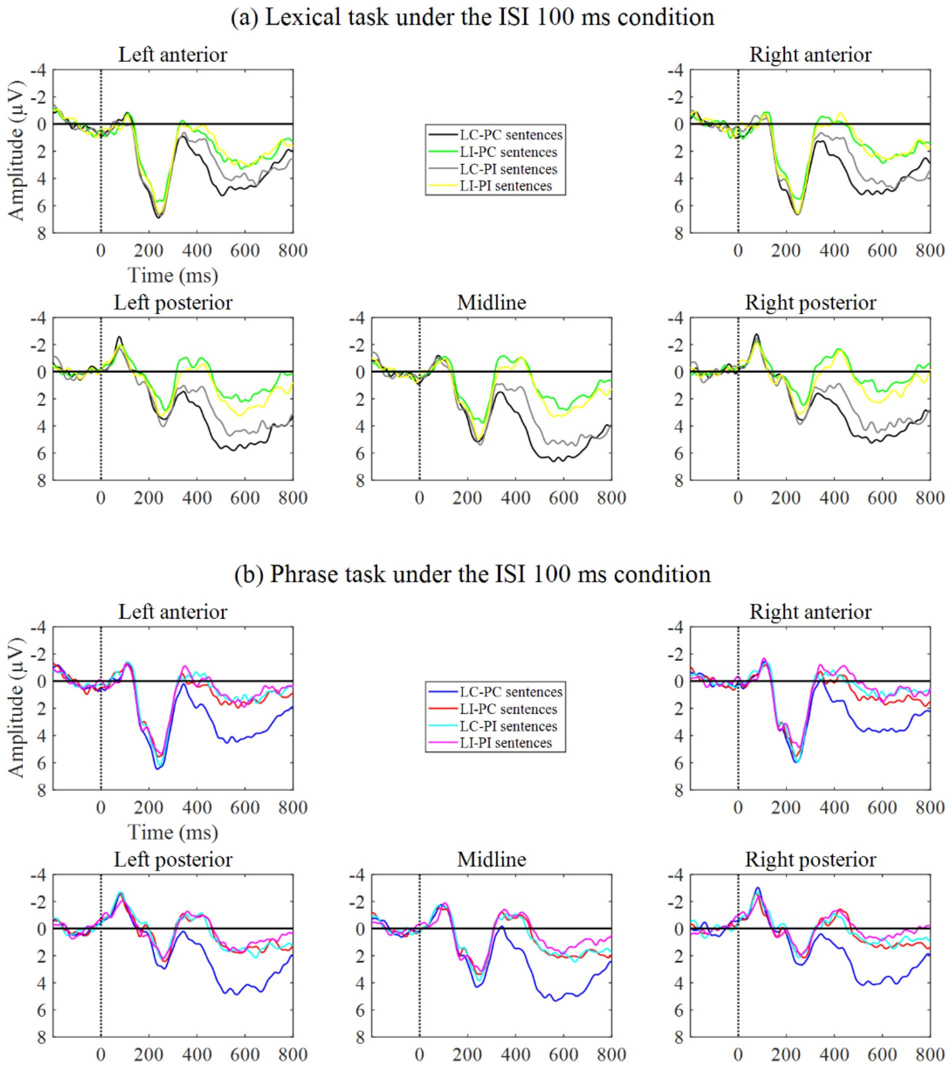

Figure 3. Grand average ERPs in the ISI 100 ms condition. The abscissa and ordinate represent time from the onset of the second phrase and amplitude of ERP, respectively. The color of each line indicates the type of judgment task and sentence presented to participants. (e.g. The black line represents that participants performed the lexical task and were presented with LC-PC sentences.) Figure 3a shows the ERP waveforms in the lexical task and Figure 3b shows those in the phrase task. See text for abbreviations of the four types of the sentences.

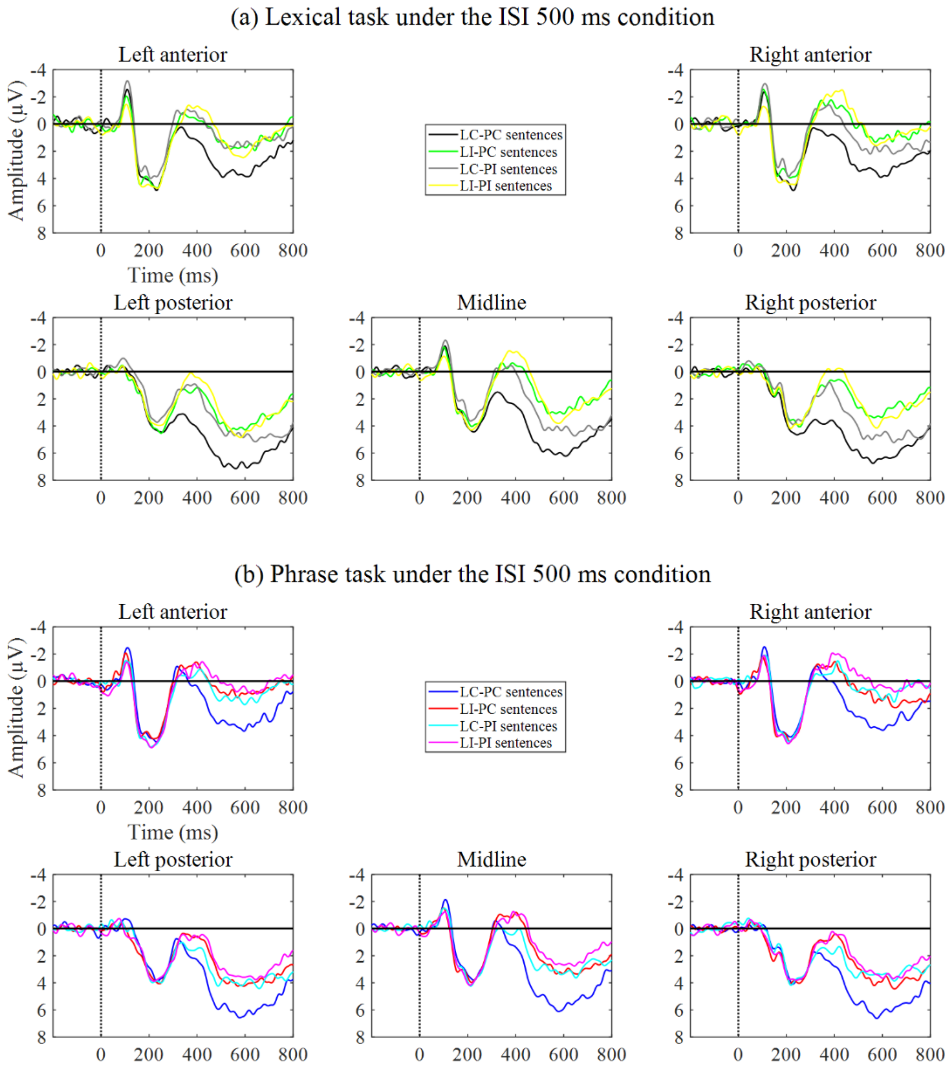

Figure 4. Grand average ERPs in the ISI 500 ms condition. Figure 4a shows the ERP waveforms in the lexical task and Figure 4b shows those in the phrase task. See Figure 3 for descriptions of the graph.

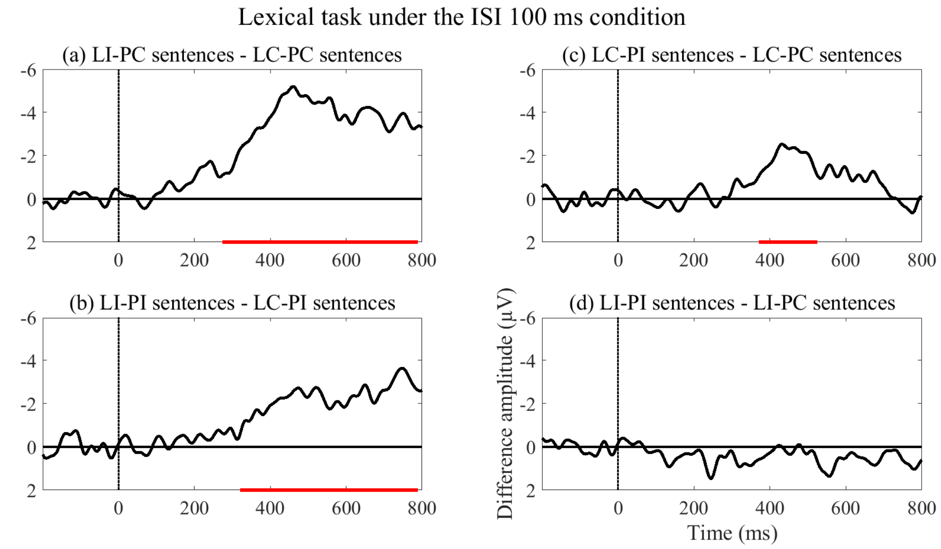

Figure 5. Difference waves among the four types of sentences in the lexical task under the ISI 100 ms condition. Each difference wave was formed by subtracting ERPs to one type of sentences from those to another type of sentences. A subtraction sign means that ERP waveforms to sentences after the sign were subtracted from those to sentences before the sign. The abscissa and ordinate represent time from the onset of the second phrase and amplitude of ERP waveforms, respectively. Red lines on the abscissa show the time periods in which significant clusters were formed based on cluster-based permutation tests. Figures 5a and 5b show difference waves between lexically incorrect and correct sentences: Figure 5a for phrasally correct sentences; Figure 5b for phrasally incorrect sentences. Figures 5c and 5d show differences waves between phrasally incorrect and correct sentences: Figure 5c for lexically correct sentences; Figure 5d for lexically incorrect sentences.

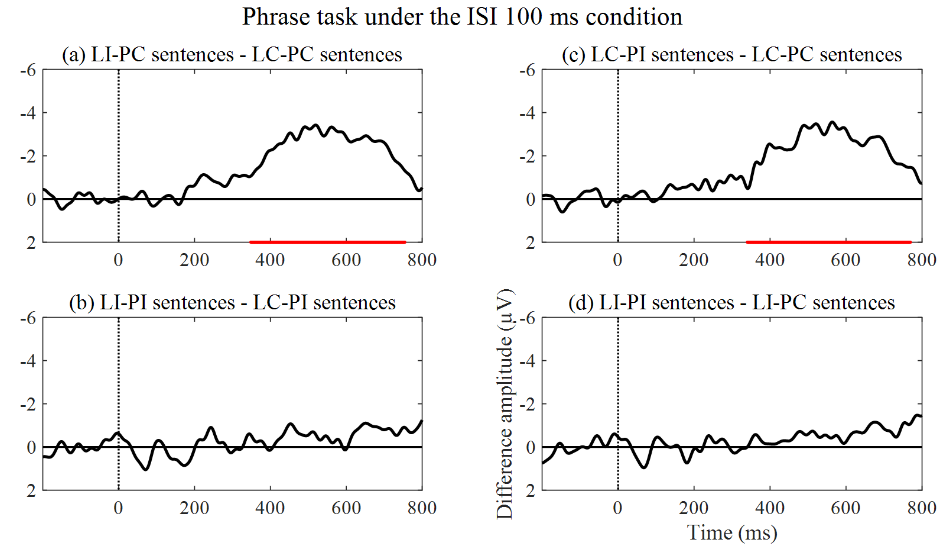

Figure 6. Difference waves among the four types of sentences in the phrase task under the ISI 100 ms condition. Figures 6a and 6b show differences waves between lexically incorrect and correct sentences: Figure 6a for phrasally correct sentences; Figure 6b for phrasally incorrect sentences. Figures 6c and 6d show difference waves between phrasally incorrect and correct sentences: Figure 6c for lexically correct sentences; Figure 6d for lexically incorrect sentences. See also figure 5 for the description of the graphs.

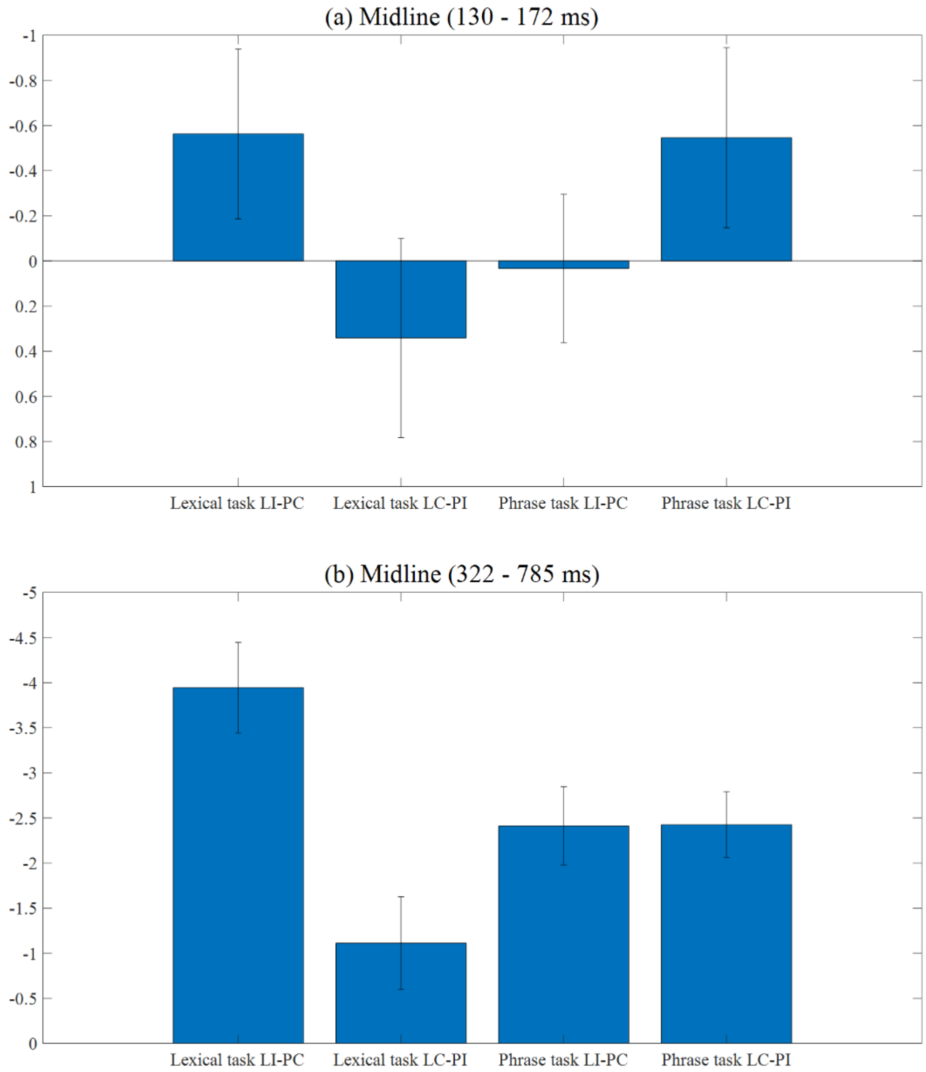

Figure 7. Mean difference amplitudes between the LI-PC or LC-PI sentences and the LC-PC sentences. Each bar was calculated by subtracting the amplitude of the LC-PC sentences from that of the LI-PC or LC-PI sentences. In each figure, two bars on the left represent difference amplitudes in the lexical task; two bars on the right represent difference amplitudes in the phrase task. Figure 7a displays the mean difference amplitudes between 130 – 172 ms; figure 7b displays the mean difference amplitudes between 322 – 785 ms. Error bars represent standard errors.

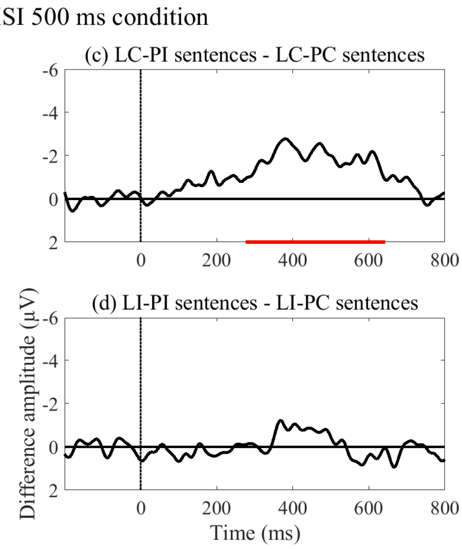

Figure 8. Difference waves among the four types of sentences in the lexical task under the ISI 500 ms condition. See figure 5 for the description of graphs.

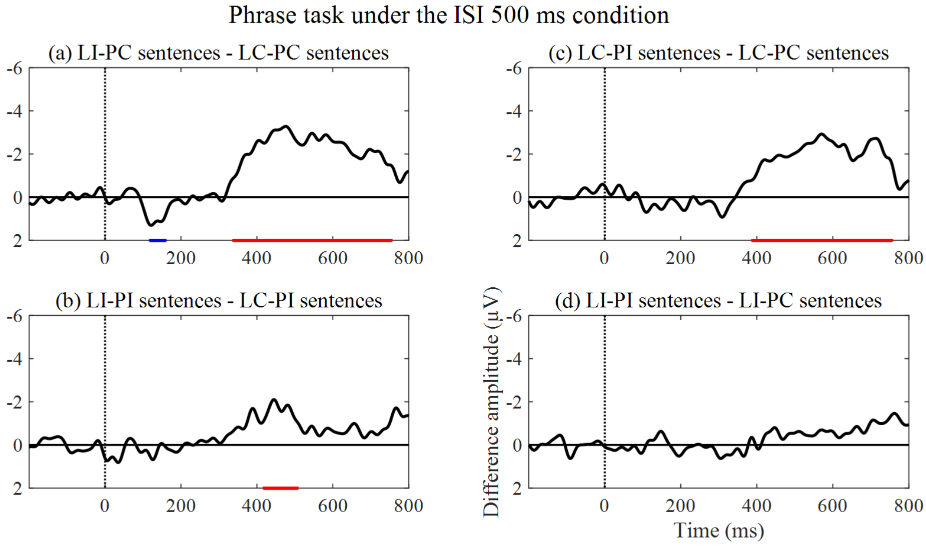

Figure 9. Difference waves among the four types of sentences in the phrase task under the ISI 500 ms condition. A blue line on the abscissa show the time periods where a statistical analysis using false discovery rate revealed significant differences. See figure 6 for the description of graphs.

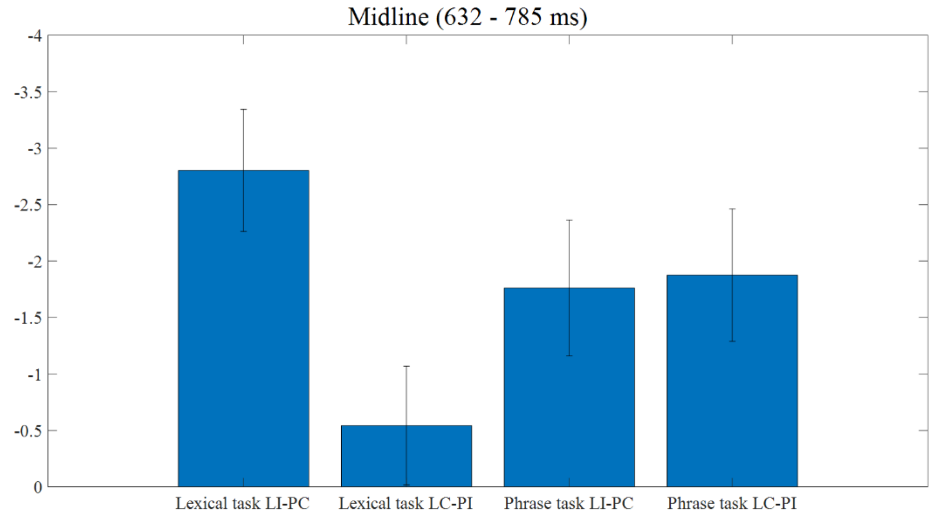

Figure 10. Mean difference amplitudes between the LI-PC or LC-PI sentences and the LC-PC sentences. The mean amplitudes were calculated from the data between 632 – 785 ms. See figure 7 for the description of graphs.

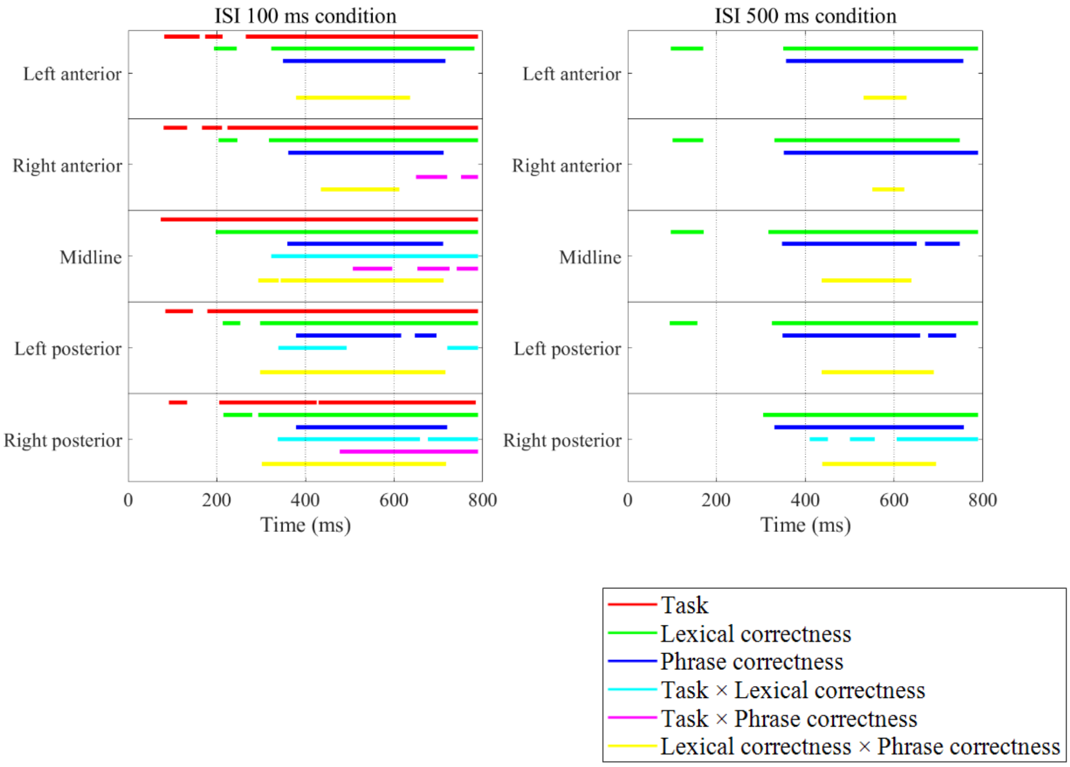

Figure 11. The result of ANOVAs for five regions on the scalp in the two ISI conditions. Each color line represents the time periods in which significant main effects or interactions were observed: red for the main effect of Task; green for the main effect of Lexical correctness; blue for the main effect of Phrase correctness; cyan for the interaction of Task × Lexical correctness; magenta for the interaction of Task × Phrase correctness; yellow for the interaction of Lexical correctness × Phrase correctness.

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